A Rare Charged Kaon Experiment at Fermilab

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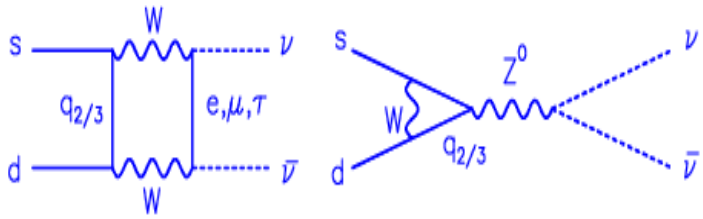
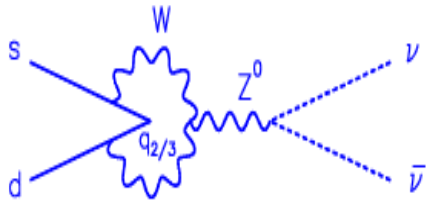
- Physics goals
- Status of CKM (E921)
- A new proposal (P940) and its challenges

Primary Physics Goal: Precision Measurement of Br[$K^+ \to \pi^+ \nu \bar{\nu}$]

This decay is determined by loop processes to high order in the SM, and hence has a reach for *new physics at the EW scale and beyond*.



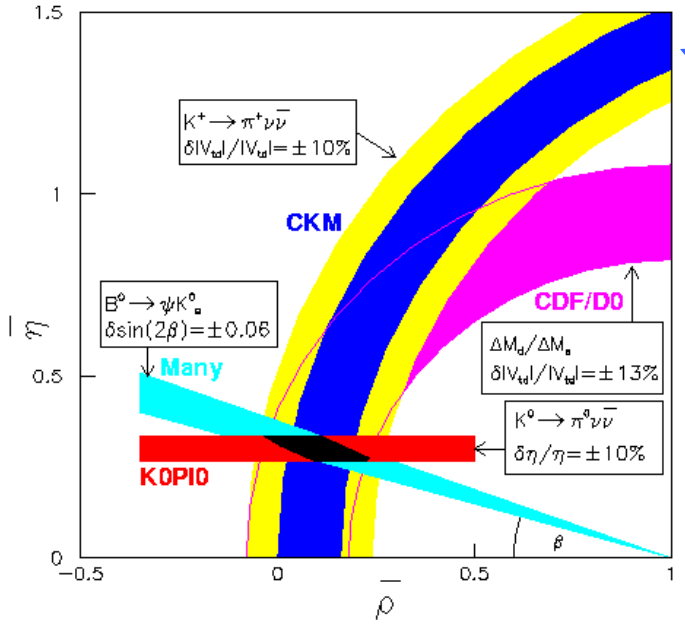
The SM rate can be reliably calculated; hence any deviation in the measured rate is a signal for new physics.



Challenging the Standard Model of CP Violation:

The quartet of "Golden Mode" measurements:

- $\sin(2\beta)$
- $\Delta m_d / \Delta m_s$ in B^0 Decays
- $K^0 \to \pi^0 \nu\bar{\nu}$
- $K^+ \to \pi^+ \nu\bar{\nu}$



Sensitivity of measurement of 100 $K^+ \to \pi^+ \nu\bar{\nu}$ events

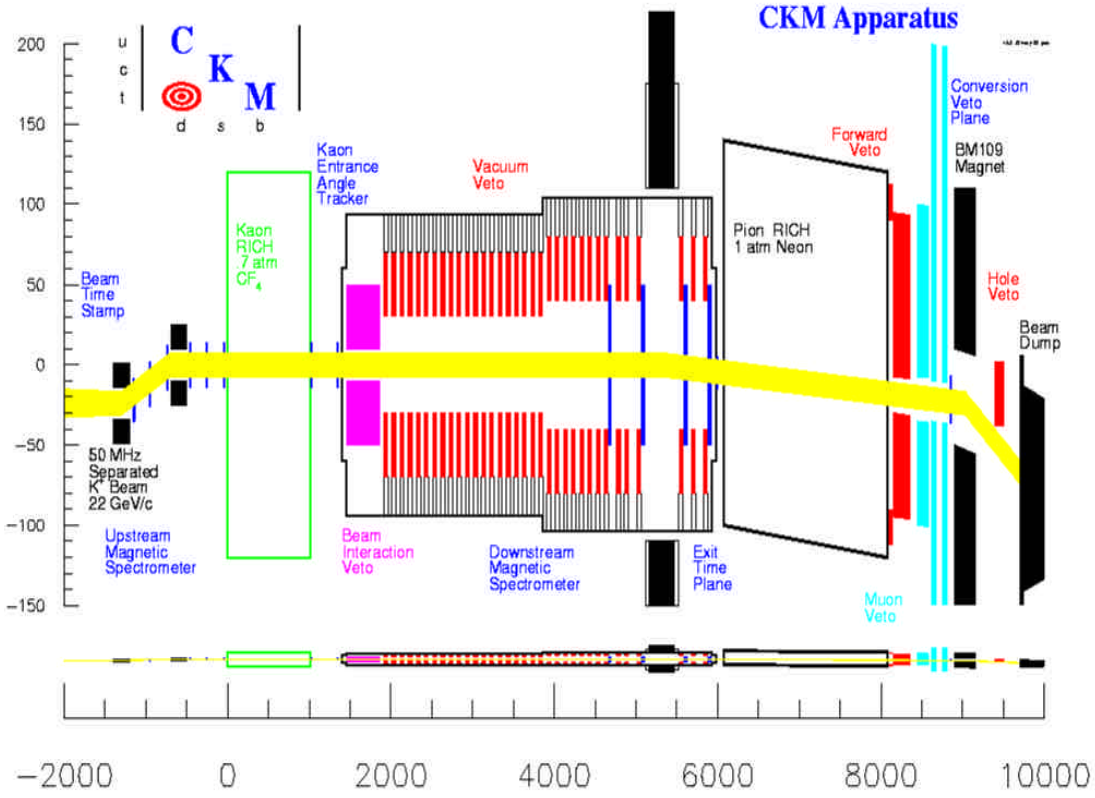
$K^+ \to \pi^+ \nu\bar{\nu}$ is sensitive to all new physics in s → d transitions

and is orthogonal to sin(2β) measurement in the B system

Measuring $|V_{td}|$ with $K^+ \rightarrow \pi^+ \nu\bar{\nu}$

- Experimental Challenge
  - Br[$K^+ \rightarrow \pi^+ \nu \bar{\nu}$] = (8±1) x 10^{-11} (Standard Model)
  - 3 clean events seen in BNL 787/949: (Br = $15\ ^{+13}_{-9}$ x 10^{-11})
  - Stopped beam experiment is limited by decay chain that includes a μ^+
- The tyranny of tiny decay rates
  - 100 events / 10^{-10} (Br) / 1% (acc) = 10^{14} K decays must be studied
  - 10^7 sec/year $\rightarrow$ 10^7 K decay /sec to see 100 in 1 year
  - Need to control background to 10^{-11} of all K decays

The CKM (E921) experiment at Fermilab



- Decay in flight
- SCRF separated beamline:
  - 30 Mhz, 22 GeV K+ beam
  - 50 Mhz total charged rate
- Redundant tracking systems:
  - Wire chambers measure momentum
  - RICH detectors measure velocity
- 34 vacuum veto modules make up vacuum decay region

History of CKM:

- P921 proposed to laboratory (April,2001)
- Director approves E921 (June,2001)
- Internal costing review (February, 2003)
- P5 reviews CKM (March 2003)
- P5 disapproves CKM (October, 2003)

Language from P5 report:

Evaluation – The subpanel was impressed with the excellent work of the proponents on the design of the experiment and their successful prototyping results. CKM is an elegant world-class experiment, which would be able to produce important physics results. However, the committee assigns it a lower priority than the BTeV experiment. The main reason is that BTeV has a much broader physics program at a comparable cost.

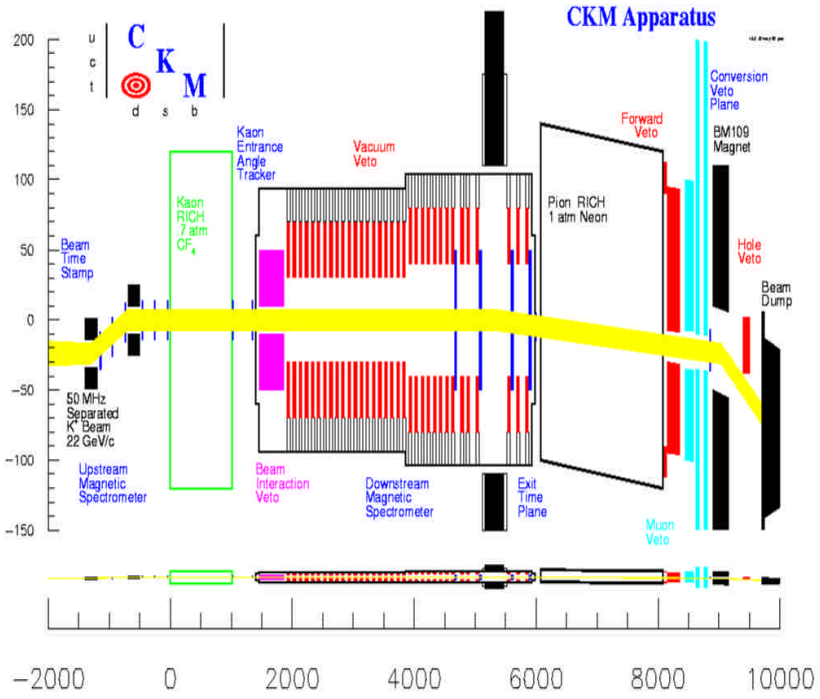
Suggestions Based on Prioritization – The present Fermilab plan calls for a similar funding profile and time-line for BTeV and CKM construction, with both starting to take data around 2009. The P5 Subpanel believes that this plan is likely to be too ambitious given the need to optimize the physics from the Tevatron Collider, as well as the desire to have BTeV completed promptly. *Based on current budgetary models, P5 does not recommend proceeding with CKM.*

How has the collaboration responded?

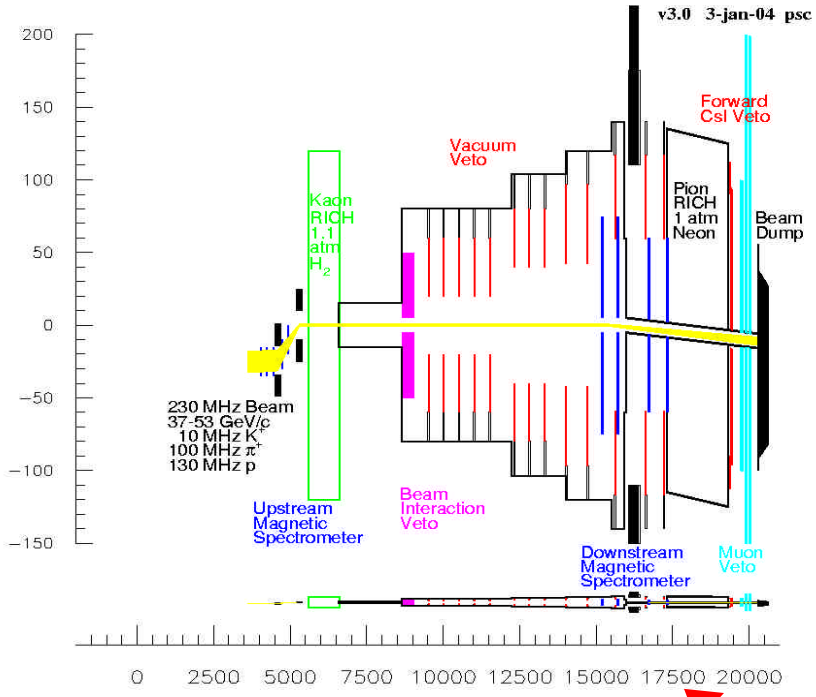
- We have reevaluated the E921 design to minimize the cost:
  - Use existing MP beamline – removes much of the construction costs
  - Descope the vacuum photon veto system, based on measured performance
  - Descope muon veto detector using KTeV system, …
- Savings using the above strategies are not enough to pass P5 review
- Largest remaining subsystem is the superconducting separated beam at 15-20M$
- Thus, we have chosen to adapt to an unseparated ~45 GeV/c beam, situated in the existing KTeV hall – **P940**
  - Demonstration of μmegas in NA48 ® tracking in 230MHz is tractable
  - Other 3 trackers unchanged (2 RICHes + Straws in vacuum)
  - Vetoing photons gets easier ($E_{\pi^0} > 1$ GeV ® >7 GeV)
  - Accidental background problem remains to be determined
  - Bottoms up cost ~25M$

Apparatus

E921: Separated K+ beam at 22 GeV/c



P940: Un-separated K+ beam at 37-53 GeV



Scale is twice as long

The Beam in P940

- High Flux Un-separated 37-53 GeV/c Beam
  - Use existing NM2 beamline and NM3-4 detector hall (KTeV)
  - Need to bring 120 GeV Main Injector beam to NM2
  - Existing target station can be modified – It is designed for required intensity
  - Proton / π^+ / K^+: 120/100/10 Mhz, in 1x1 cm^2, 0.1x0.1 $mRad^2$
  - 1.7 MHz of kaon decays in the spectrometer acceptance.
  - 5 x10^{12} 120 GeV proton /sec in slow spill from the Main Injector to produce the required K^+ beam..

Changes to the apparatus

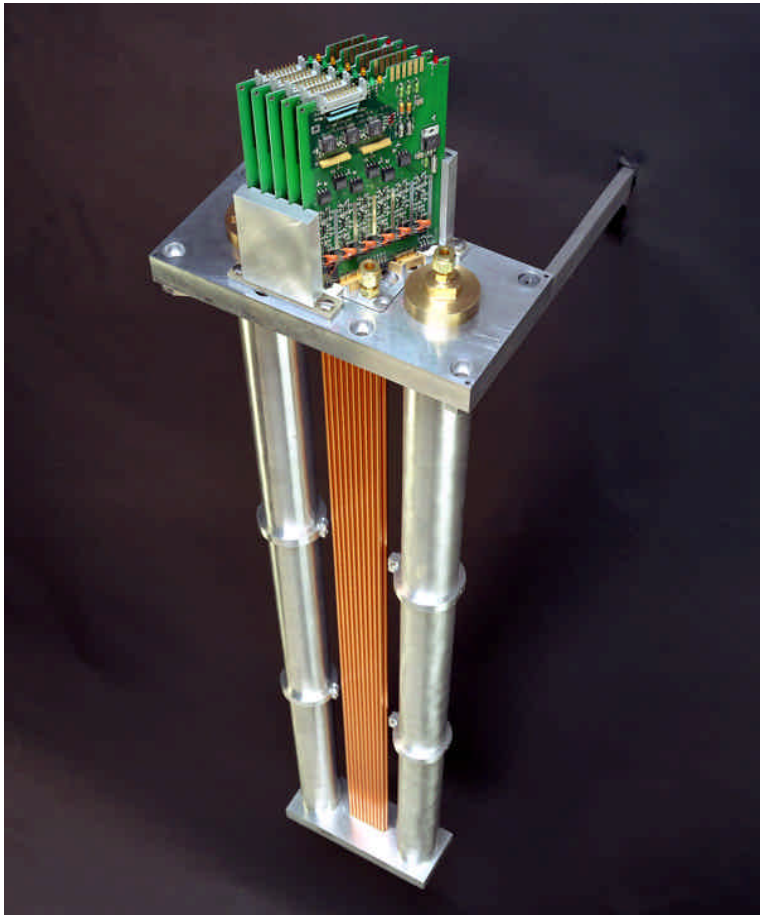
- Kaon RICH: 10 → 12m, radiator gas to H_2 at 1.1 atm – only sees beam Kaons
- DMS: same strawtube in vacuum design as CKM, hole for 10cm beampipe
- Pion RICH:
  - Same basic design as CKM (1atm Ne, 3000 1/2in PMTs)
  - Optics modified to accommodate beampipe down the middle.
- Photon Vetoes:
  - 90% of photons now hit the forward CsI veto with $1-\varepsilon \sim 3\times10^{-6}$ for E>1 GeV
  - VVS - 5 existing Pb-scint rings from KTeV + 9 new ones of CKM design
  - Photon energy threshold can be >1.5 MIP everywhere.
- Muon Vetoes: combined KTeV MVS + descoped CKM design
- UMS: Develop a new high rate tracker for the incoming beam, to handle the 230 MHz rate.
  → MicroMegas technology

Other Physics Measurements

- π^+ decay physics
  - $\Gamma[\pi^+ \to e^+\nu(\gamma)]/\ \Gamma[\pi^+ \to \mu^+\nu(\gamma)]$ is calculated to 0.05% in the SM
  - Helicity suppresses the dominant V-A and IB amplitudes
  - $\pi^+ \to e^+\nu\gamma$ Dalitz plot – access to non V-A terms in hadronic weak current
  - An excellent place to search for models like leptoquarks, multiple Higg, etc.
- Other K^+ decay physics
  - Many other kaon decays would benefit from a new dedicated facility:
    - K_{e3}, K_{e4}, $K_{\mu 3}$, $K_{\mu 4}$, $K^+ \to \pi^+ e^+ e^-$, $K^+ \to \pi^+ \mu^+ \mu^-$
    - Lepton flavor violation - $K^+ \to \pi^- \mu^+ \mu^+$, etc.
    - T odd correlations in $K^+ \to \pi^+ l^+ \nu\gamma$
  - $\Gamma[K^+ \to e^+\nu(\gamma)]/\ \Gamma[K^+ \to \mu^+\nu(\gamma)]$ in parallel with pion decays

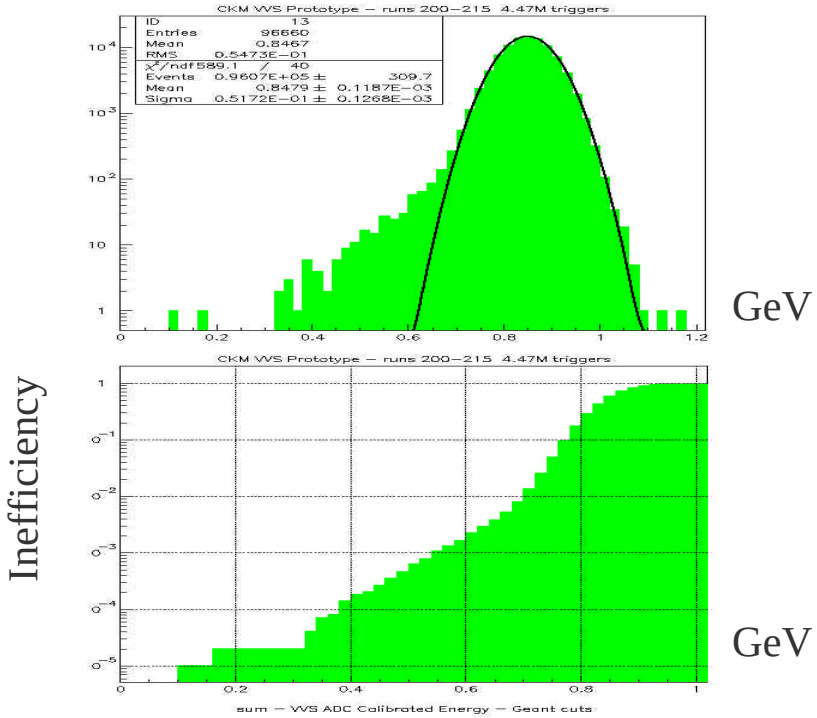
Straws in Vacuum: a solved problem

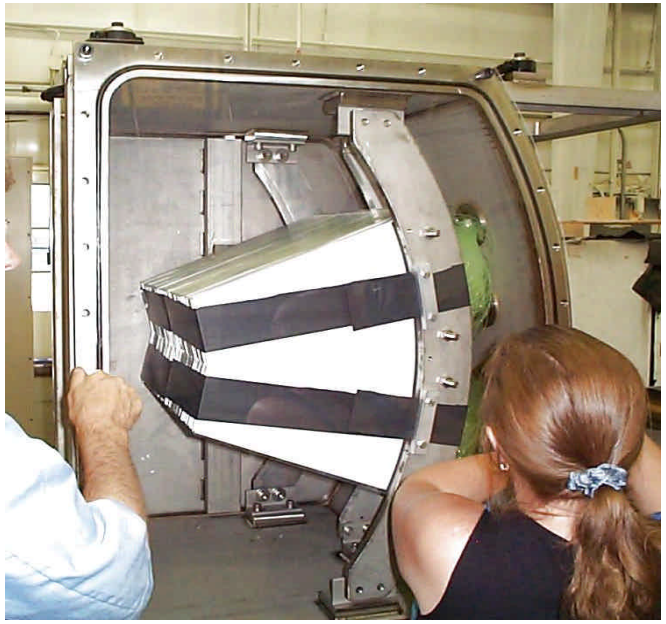
- Mechanical properties extensively studied. (Fermi-Pub 02-241-E)
- 2 prototypes operating in vacuum.
- Proven Principle. Now ready for detailed engineering.



Photon Veto Technology and Inefficiency

- 2/16 sector prototype built – 80 layers of 1 mm Pb/5 mm scint
- Tested at JLAB in an e^- beam
- Achieved 3×10^{-6} veto inefficiency at 1 GeV (required 3×10^{-5})



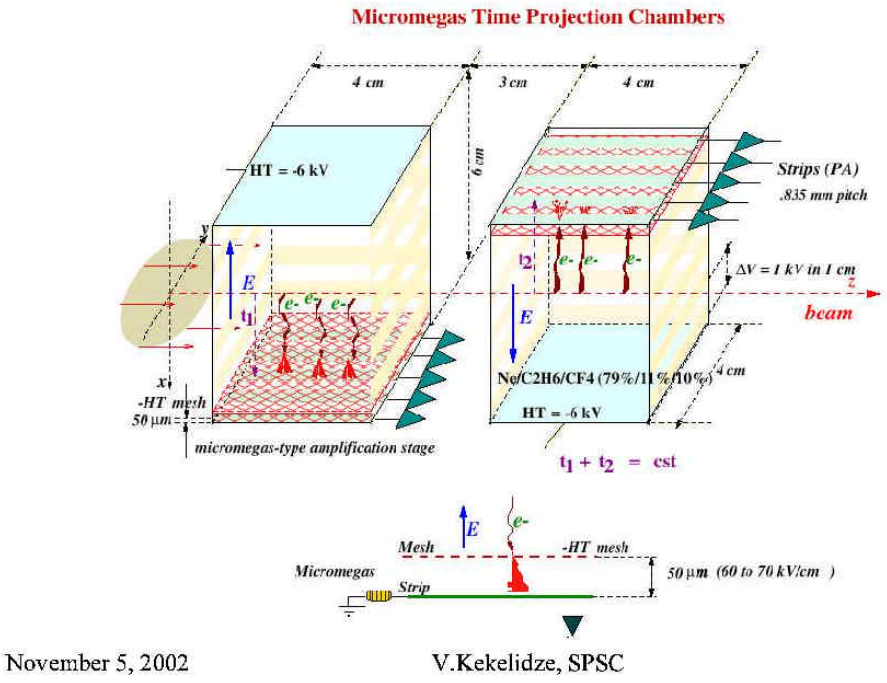


KABES μMEGAS from NA48

V.Kekelidze

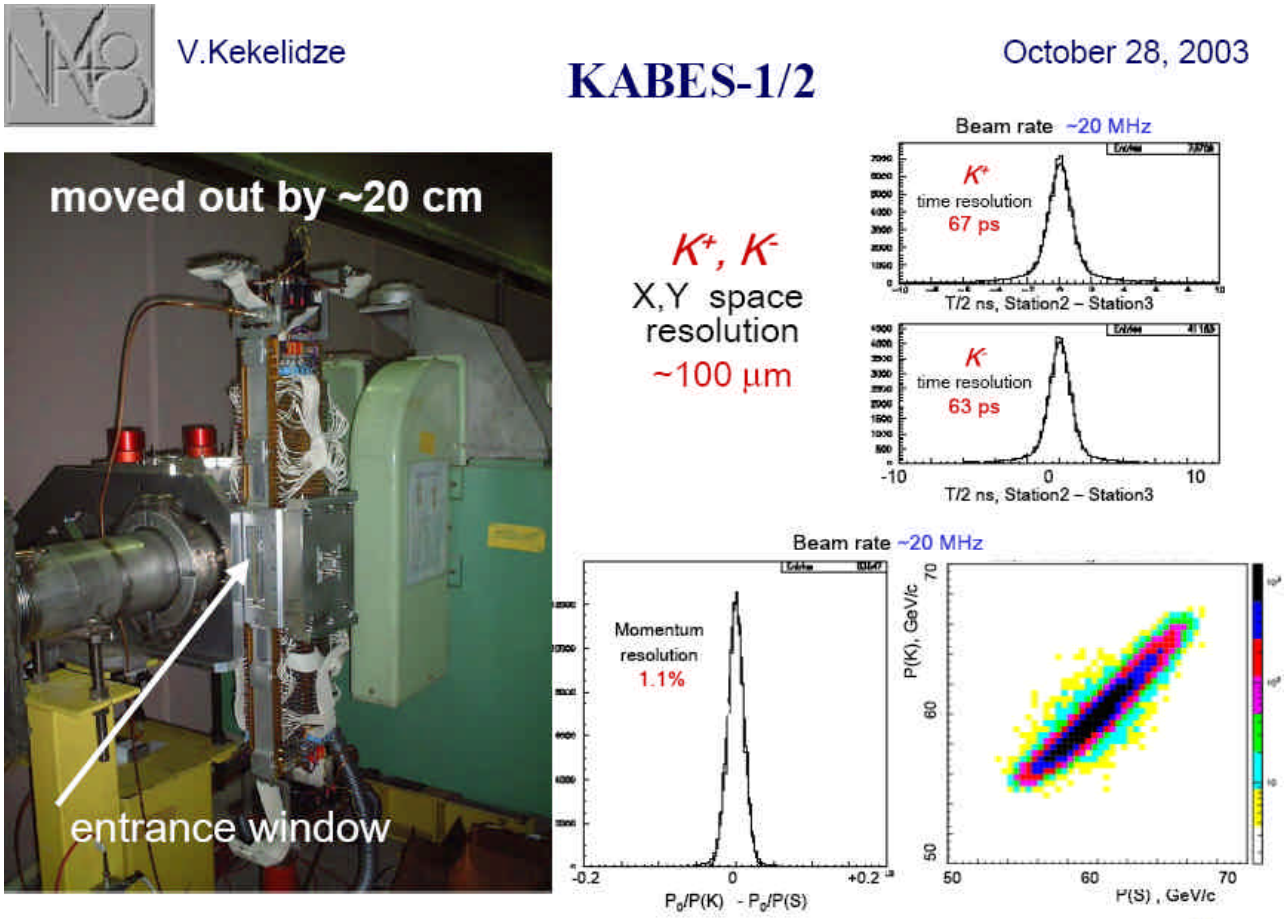
New elements for NA48/2

Beam Spectrometer KABES (TPC micromegas)



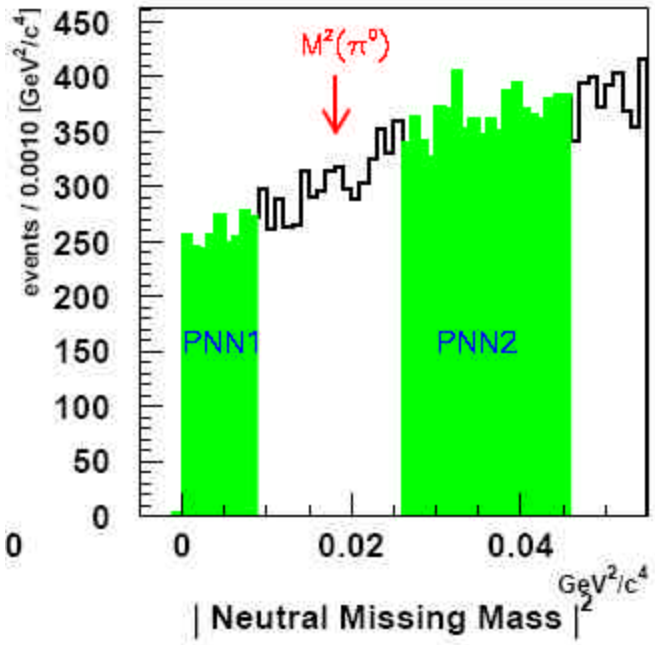
November 5, 2002 V.Kekelidze, SPSC

NA48 KABES data



Acceptance

- Decay fraction increased 13% → 16.5%
- PNN2 acceptance assumed to be 1.4x PNN1, pending more serious simulation studies



parameter	CKM (E921)	P940
$K^+ flux[MHz]$	30	10
beam-sec/year	0.75×10^7	0.75×10^7
years of data	2	2
sensitive K decays	5.8×10^{13}	2.5×10^{13}
nominal Branching ratio	1×10^{-10}	1×10^{-10}
taxes (other losses)	-15%	-15%
PNN1 (s+b)	$95+ \leq 10$	$44+ \leq 4$
PNN2	$(130+ \leq 40)$	$62+ \leq 20$
total	$95+ \leq 10$	$106+ \leq 24$
Br precision	$< 11\%$	$< 12\%$

Backgrounds Remaining

Background Source	Effective BR ($\times 10^{-12}$) CKM	P940
• $K^+ \rightarrow \mu^+ \nu_\mu$	< 0.04	-
• $K^+ \rightarrow \pi^+ \pi^0$	3.7	~5
• $K^+ \rightarrow \mu^+ \nu_\mu \gamma$	< 0.09	-
• $K^+ A \rightarrow X K^0_L \rightarrow \pi^+ e^- \nu$	< 0.14	TBD
• $K^+ A \rightarrow \pi^+ X$ (trackers)	< 4.0	TBD
• $K^+ A \rightarrow \pi^+ X$ (gas)	< 2.1	TBD
• Accidentals (K^+ + beam track)	-	TBD
• Accidentals (2 K^+)	0.51	0.17
• TOTAL	<10.6	TBD

Our plan

- We are in the middle of this redesign now – we need to:
  - Complete the unseparated beamline design for NM2
  - Assess KABES feasibility in a 230 MHz beam
  - Re-evaluate backgrounds from Kaon interaction in detectors
  - Estimate backgrounds from non-kaon interaction accidentals
  - Evaluate PNN2 cuts, acceptance and backgrounds
  - Re-assess losses from deadtime, reconstruction, …
- Our Plan
  - Complete the list above
  - Have external technical review of the redesign (a-la CKM)
  - Return to Fermilab and the PAC with a vetted re-design
  - Time scale of months